Astronomy & Astrophysics manuscript no.
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Spectra of binaries classified as λ Boo stars *

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Abstract. High angular resolution observations have shown that some stars classified as λ Boo are binaries with low values of angular separation and magnitude difference of the components; therefore the observed spectrum of these objects is a combination of those of the two components. These composite spectra have been used to define spectroscopic criteria able to detect other binaries among stars classified as λ Boo . The application of this method to HD 111786 is presented: the contribution of 5 components to the observed spectrum is demonstrated by the shape of the O I 7774 Å feature. This result makes unreliable any attempt to perform an abundance analysis of this object which therefore must be definitely rejected from the class of the peculiar λ Boo stars. This approach allowed us also to recognize that the SB2 star HD 153808 is in reality a triple system.

Key words. 08.01.1 Stars: abundances - 08.01.3 Stars: atmospheres - 08.03.2 Stars: Chemically Peculiar - 08.02.1 Stars: binaries: close - 08.02.4 Stars: binaries: spectroscopic - 08.02.6 Stars: binaries: visual

1. Introduction

Metal underabundances are not common among young A-type stars; following the description of the λ Boo spectrum by Morgan et al (1943), Burbidge & Burbidge (1956) made a first abundance analysis of other metal-weak stars which are now known to belong to both λ Boo and field HB classes. Sargent (1965a and 1965b) was the first to list the criteria to select the Population I early A-type λ Boo stars. Later on, Slettebak et al (1968) gave a more detailed spectroscopic definition as well as the criteria to distinguish λ Boo stars from other metal weak stars. One of the specified characteristics is the moderately large rotational velocity (usually 100-150 $\mathrm{km\,s^{-1}}$) which clearly represented a difficulty for abundance analyses performed with the curve of growth method and based on photographically recorded spectra. In fact, the only detailed study of the abundance peculiarities before the advent of modern detectors is that by Baschek & Searle (1969).

Systematic spectroscopic and photometric search for new members of the class have been performed mainly in the past two decades. The spectroscopic characteristics in classification dispersion covering the optical range are extensively described by Gray (1997) who gave a new definition and more detailed classification criteria to select these objects.

The comparison of the Gray's definition with the earlier ones shows that the new definition includes also later spectral types up to early F-type and stars with low $v \sin i$ values.

Modern detailed abundance analyses are still scanty and concern a very limited number of objects (e.g. Venn & Lambert, 1990; Stürenburg, 1993), but sufficient to note that the metal deficiency is widely variable from star to star with a large scatter of pattern behaviour. All the abundance analyses (with the exception of that on HD

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* Based on data from ESO, Observatoire du Pic du Midi, IUE Final Archive and on observations obtained with the Hipparcos satellite.

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84948, see below) are based on the hypothesis that λ Boo stars are single objects. In this paper we investigate spectroscopic criteria to detect duplicity among these stars.

In the meantime theories to explain the λ Boo phenomenon have been proposed, but none is definitely accepted. In fact, the λ Boo phenomenon is complicated; for example several stars show one or more of the following peculiarities: an IR excess, photometric variability, short term pulsation or narrow absorption lines, indicating the presence of a shell. Some stars instead show none of the above.

Faraggiana & Bonifacio (1997) proposed a new interpretation of these objects; they analyzed the combined list of λ Boo candidates extracted from three different and recent sources and noticed that a considerable number of these λ Boo candidates are detected or suspected binaries. In the present paper we discuss how it is possible to recognize a composite spectrum of a moderately high rotating star ($v \sin i$ up to about 100 $\mathrm{km\,s^{-1}}$) through the comparison of observed and computed spectra. In fact high resolution combined with low noise spectra are quite easily obtainable with modern equipment and allow one to detect a number of previously unsuspected binaries.

A search for spectral features which can be used as duplicity criteria for A-F stars can find application on a much wider field than that of stars more or less questionably classified as λ Boo .

The stars used to select spectroscopic signs of duplicity are chosen among those found to be SB2 spectroscopic binaries or binaries with a separation less than 1 arcsec measured by speckle interferometry and/or extracted from the Hipparcos Catalogue (ESA, 1997) and a magnitude difference of less than 1.5 mag. The spectra of 5 binaries, 4 of which classified as λ Boo stars (HD 38545, HD 47152, HD 84948 and HD 153808) by at least one author and one (HD 18622) classified as normal star, are discussed and the spectroscopic criteria that reveal their duplicity investigated.

A first application to HD 111786, classified as λ Boo by Gray (1988), is given in this paper; Faraggiana et al (1997) have discovered a companion through the presence of the narrow lines previously interpreted as originating from a shell around a single rapidly rotating object. The present analysis of the O I triplet at 7774 Å in particular demonstrates that in reality HD 111786 is formed by a clump of stars with similar luminosity and therefore any classification and abundance analysis of this object must be considered unreliable.

2. Classification and duplicity data for the selected sample of binaries

The five already known binary stars which have been selected for the search of duplicity signatures in their spectrum are listed in Table 1. The V magnitudes and the spectral types are taken from the Bright Star Catalogue (Hoffleit & Warren, 1994); the parallaxes and errors, measured in milliarcsec (mas) and the Hipparcos magnitudes

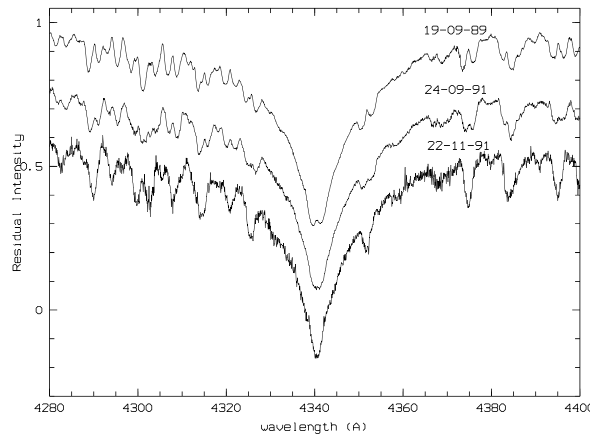

Fig. 1. The spectrum of the SB2 star HD 18622 in the region of H_γ at different dates.

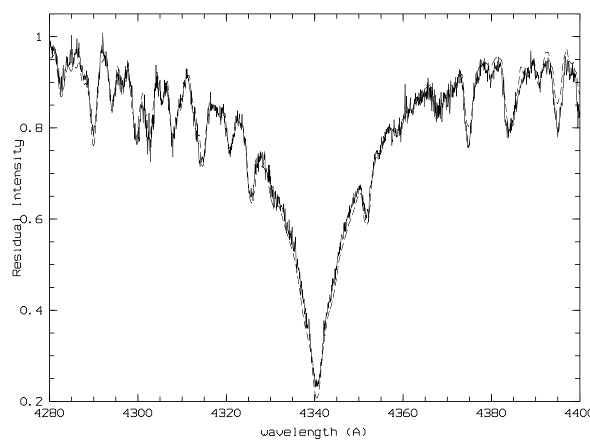

Fig. 2. The spectrum of HD 18622 taken on 22 Nov 1991 superimposed on the computed one (dashed line).

(Hp) are from the Hipparcos Catalogue (ESA, 1997). The angular separations are from the same source for all but the last star; the value for HD 153808 is that given in the Washington Visual Double Star (WDS) catalogue (Worley & Douglass, 1997).

The sources of information for the spectroscopic binaries are Corbally (1984) for HD 18622, Paunzen et al (1998) for HD 84948, and Petrie (1939) for HD 153808.

HD 18622 Non peculiar star, classified A3 V (Bright Star Catalogue, 1964 ed), A4 III (CDS) or A5 IV (Gray & Garrison 1989). This star belongs to the catalog of $v \sin i$ standard stars by Slettebak et al (1975) and to the list of standard stars for H_α photometry by Strauss and Ducati (1981). The star has a visual companion, HD 18623, at 8.3 arcsec with a Δm=1.1; so it is an example of a spectroscopic binary with a more distant visual companion. The only references to its SB2 nature we aware of are in the Bright Star Catalogue (since the 1982 ed.), and in Corbally (1984).

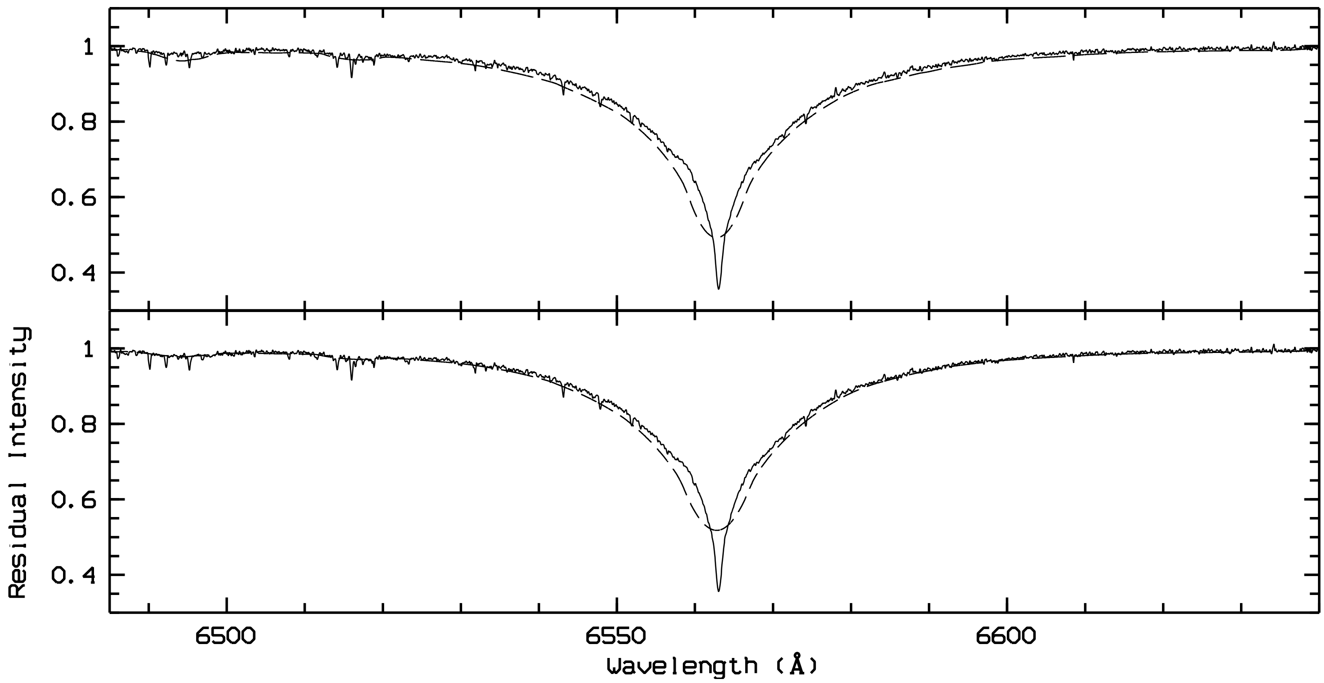

Fig. 3. The observed spectrum of HD 38545 in the region of H_α compared with two synthetic spectra (dashed line): that computed with the parameters given in Table 3 (top: $T_{\rm eff}$ =8500 K, log g=3.6, $v \sin i$ =175 km s^{-1}) and that computed with the St93 parameters (bottom: $T_{\rm eff}$ =9000 K, log g=3.6, $v \sin i$=200 km s^{-1}).

Table 1. Observational data; V and spectral type are from the Bright Star Catalogue (Hoffleit & Warren, 1994) for all but HD 84948 whose values are taken from the CDS database; in Column 9 the authors who classified as λ Boo are given (G= Gray, 1997; CC= Paunzen et al, 1997; AM= Abt & Morrell, 1995) for all but the first star.

HD	V	Sp. Type BSC	π mas	$\sigma(\pi)$ mas	Hp(A)	Hp(B)	Sep. arcsec	Class.	Rem.
18622	3.24	A5 IV	20.22	0.54	3.278	4.423	8.310	st. $v \sin i$	SB2
38545	5.72	A3 Vn	7.72	0.93	6.229	6.87	0.155	Gray, CC	speckle
47152	5.79	B9npEu	7.74	1.08	6.201	6.969	0.210	AM	speckle
84948	8.13	F0	4.97	1.14	–	–	–	CC	SB2
153808	3.92	A0 V	20.04	0.65			0.2	AM	SBO

HD 38545 Classified λ Boo by Gray & Garrison (1987); the presence of shell lines has been noted first by Stürenburg (1993) and since then studied both in the visual (Bohlender & Walker, 1994; Andrillat et al, 1995; Hauck et al, 1995 and 1998; Holweger & Rentzsch-Holm, 1995; Holweger et al, 1999; Hauck and Jaschek, 2000) and in the UV range (Grady et al, 1996). The binary nature of this object has been discovered by McAlister et al (1993) and confirmed by Hipparcos (ESA, 1997) and new speckle data (Marchetti et al, 2001).

According to the Bright Star Catalogue (since its 1982 ed.), this star has a variable radial velocity whose origin has never been studied.

HD 47152 Classified either Ap of Hg,4077 type (Osawa, 1965) or λ Boo (Abt & Morrell, 1995), but excluded from the λ Boo class by Hauck et al (1998) who recall the agreement of the Osawa classification with the Geneva Δ(V1-G) parameter. In spite of the numerous speckle observations since 1982 indicating the presence of a companion (McAlister & Hendry, 1982; Bonneau et al 1984; etc.), the duplicity is ignored in all the spectroscopic studies of its peculiarities.

The values of the angular separation and the magnitude difference given by Hipparcos, are such that only a composite spectrum can be observed; so the star cannot be safely assigned either to the Ap class or to that of λ Boo stars by neglecting its duplicity.

HD 84948 The classification as possible λ Boo is due to Abt (1984); Andrillat et al (1995) on the basis of near-IR spectra classified it as λ Boo with shell; Paunzen and Gray (1997) note the similarity with HD 84123 spectrum and suggest that both are perhaps field HB stars; Paunzen et al (1998) performed an abundance analysis based on an echelle spectrum of this resolved SB2 object (range 4000-5700 Å), extended to Na through unquoted observational data.

HD 153808 Intriguing object for which there are discordant results on its duplicity as a visual binary.

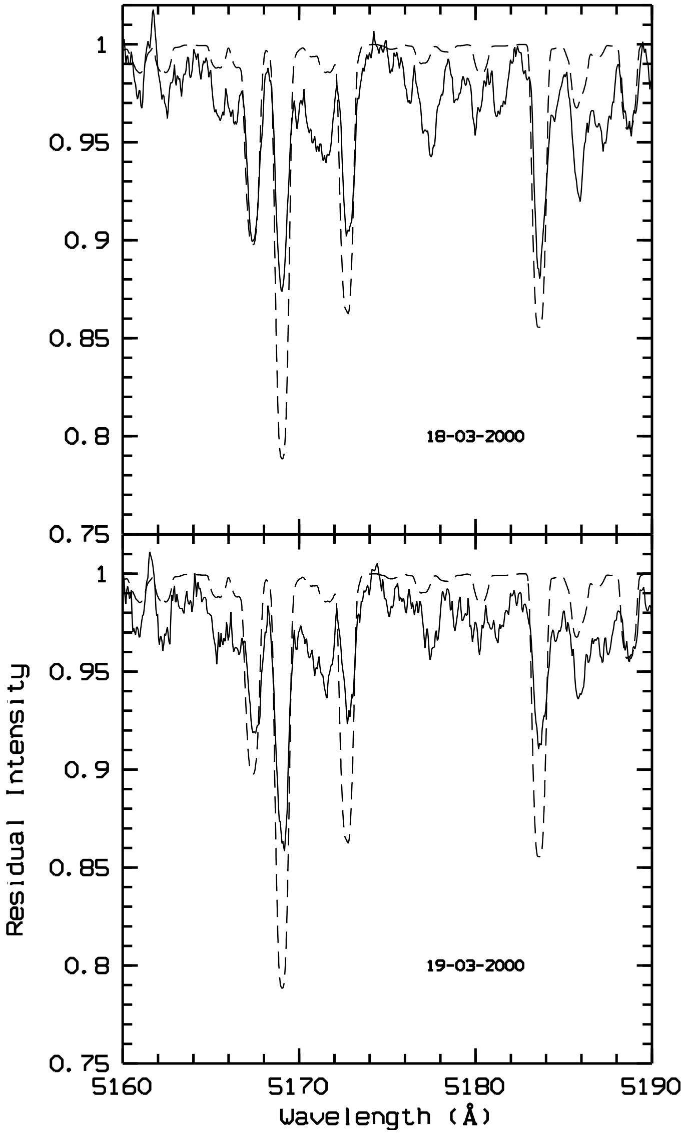

Fig. 4. The spectrum of HD 47152 in the region 5160-5190 Å shows the poor fit with the computed spectrum (dashed line), the high number of unidentified lines and the variability of the Mg I triplet in 1 day.

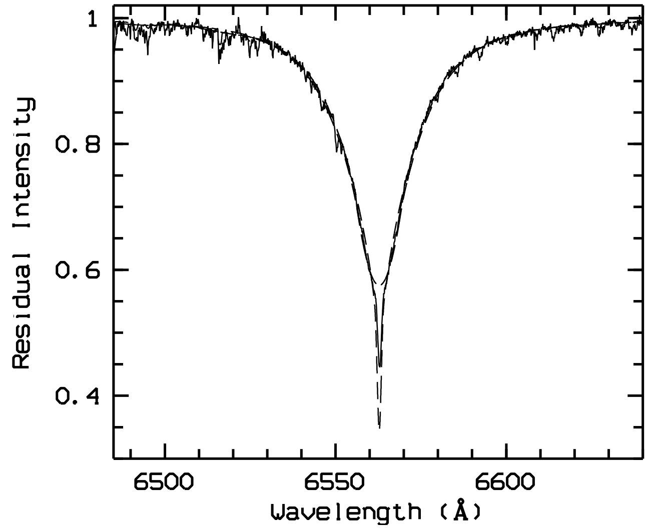

Fig. 5. The Hα profile of HD 47152 compared with two synthetic spectra both computed with $T_{\rm eff}$ = 10000 K, log g= 4.0 and two values of the broadening 30 and 300 km s^{-1}.

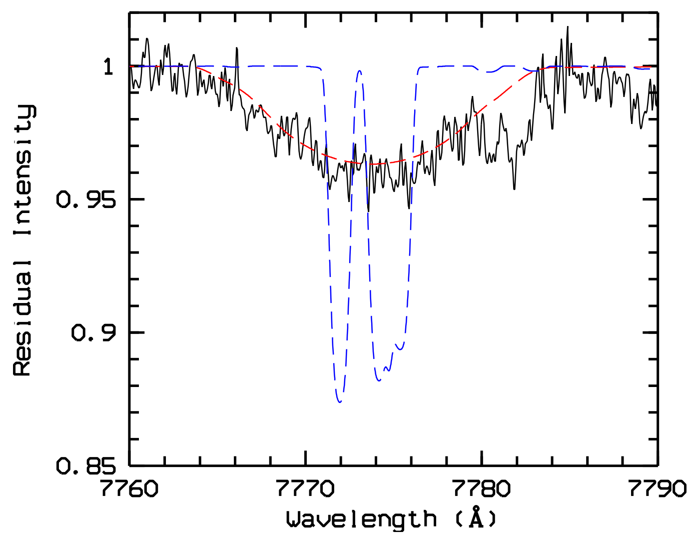

Fig. 6. The O I triplet 7772-7775 is not resolved in the spectrum of HD 47152, as it should be expected from the other narrow metal lines; The computed spectra (dashed lines) have been broadened by 30 km s^{-1}and 300 km s^{-1}respectively.

Hipparcos did not detect any sign of duplicity nor is its duplicity mentioned in the Hipparcos Input Catalogue (Turon et al, 1993). Controversial visual binary detections are reported in the literature, the two values of the separation 0.24 and 0.97 arcsec measured by Isobe et al (1990 and 1992), being not confirmed by other authors.

As a spectroscopic binary this object has been studied in the past; the period, P=4.0235 d as well as the other orbital elements are given in the Batten et al (1989) catalogue, but are based only on the measures by Luyten (1936). The double-lined spectrum is discussed by Petrie (1939) who classified the two components A0 and A2 and computed a magnitude difference of 1.5.

It is classified also as Mn star (e.g. Wolff & Preston, 1978), or normal A0IV^{+} by Gray & Garrison (1987) and quoted as SB2 by Wolff (1978).

The values of the projected rotational velocity vary considerably from author to author: 38 km s^{-1} (Lambert et al, 1986); 50 km s^{-1} (Abt & Morrell, 1995); 80 km s^{-1} (Wolff & Preston 1978); 90 km s^{-1} (Slettebak, 1954).

It is included in the Tokovinin (1997) catalogue of triple systems; this author considers doubtful the binary detection of the visual AB system since it is not confirmed by the Hipparcos data, but retains the spectroscopic duplicity Aab.

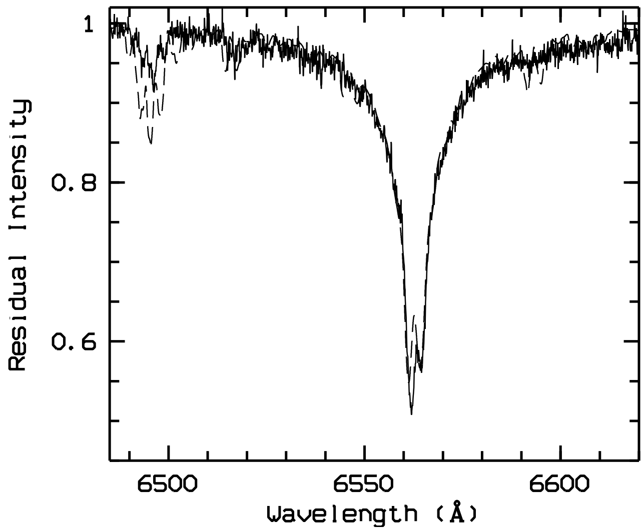

Fig. 7. The observed H_α profile of the SB2 star HD 84948 compared with the spectrum (dashed line) obtained by combining two computed spectra (see text).

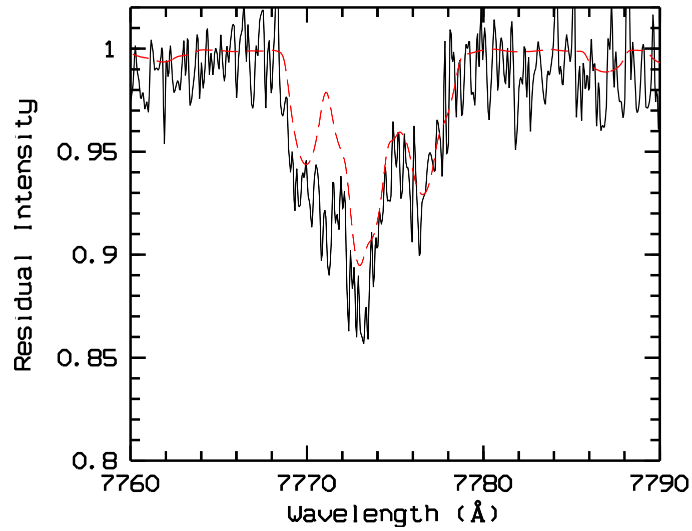

Fig. 9. The region of the O I triplet of HD 84948 compared with the same combination of spectra used for figures 7 and 8 (see text).

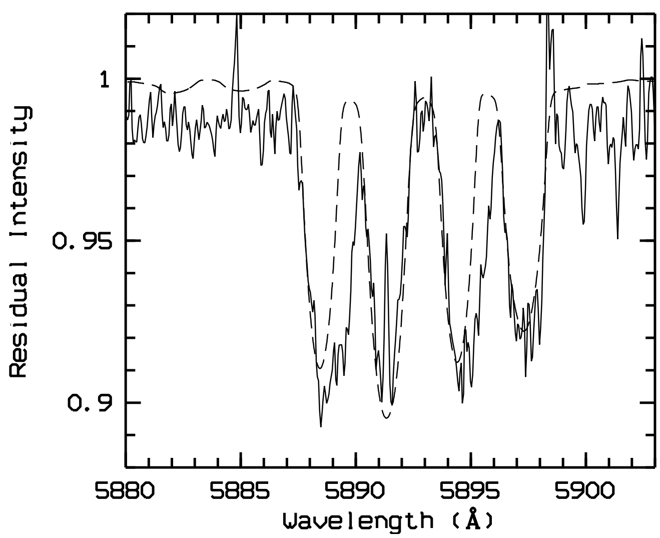

Fig. 8. The region of the Na I doublet of HD 84948 compared with the spectrum computed with the same combination of models used for Fig. 7.

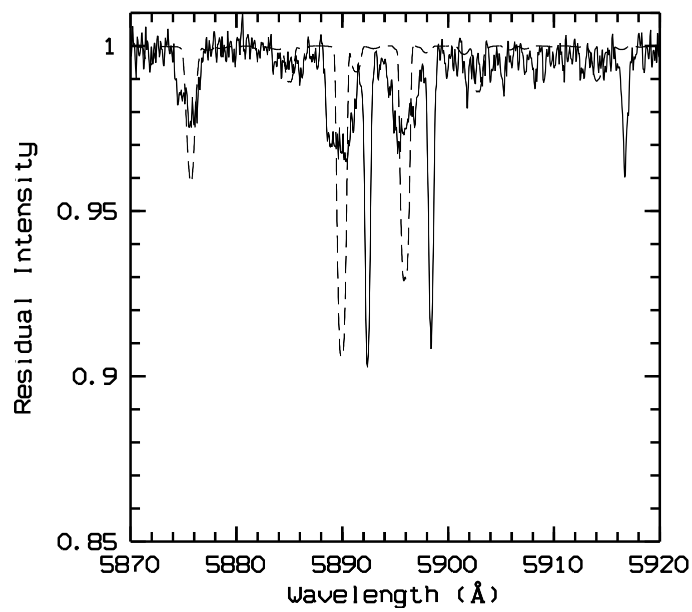

Fig. 11. The duplicity of the blue-shifted component star of HD 153808 is clear from the Na I doublet and the He I 5876 profiles compared with the computed spectrum (broken line) from the same model used for Fig. 10.

3. Observations

The optical spectra have been collected at the Echelec (ESO), Musicos (Observatoire du Pic du Midi) and FEROS (ESO) spectrographs which have a nominal resolution of about 28000, 38000 and 48000 respectively; the wavelength range of each of them is broad enough to include at least one Balmer line. The journal of observations is given in Table 2.

3.1. Echelec data

The Echelec spectrograph was mounted at the Cassegrain focus of the ESO 1.52 m telescope at La Silla; our spectra cover the 4200-4500 Å spectral range; the S/N ratio is not constant and highly variable between the centre and the edges of each echelle order. The spectra have been reduced with the package written by Burnage & Gerbaldi (1990 and 1992) and running under MIDAS.

3.2. FEROS data

The HD 111786 spectrum has been taken with the new high resolution spectrograph FEROS (Kaufer et al. 1999) installed at the Coudé focus of the ESO 1.5m telescope at La Silla. This spectrograph is a bench-mounted fiber-fed

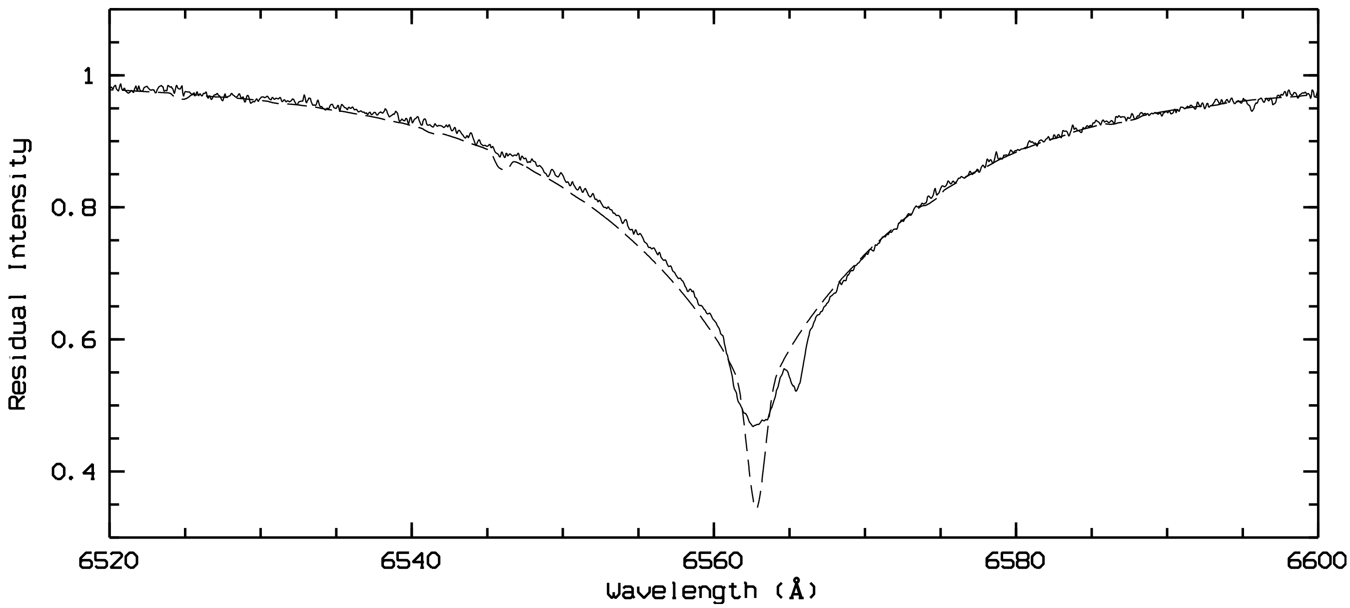

Fig. 10. The observed profile of H_α of HD 153808 compared with that computed from a model with $T_{\rm eff}$ =10000 K, log g= 4, broadening=30 $\rm km\,s^{-1}$.

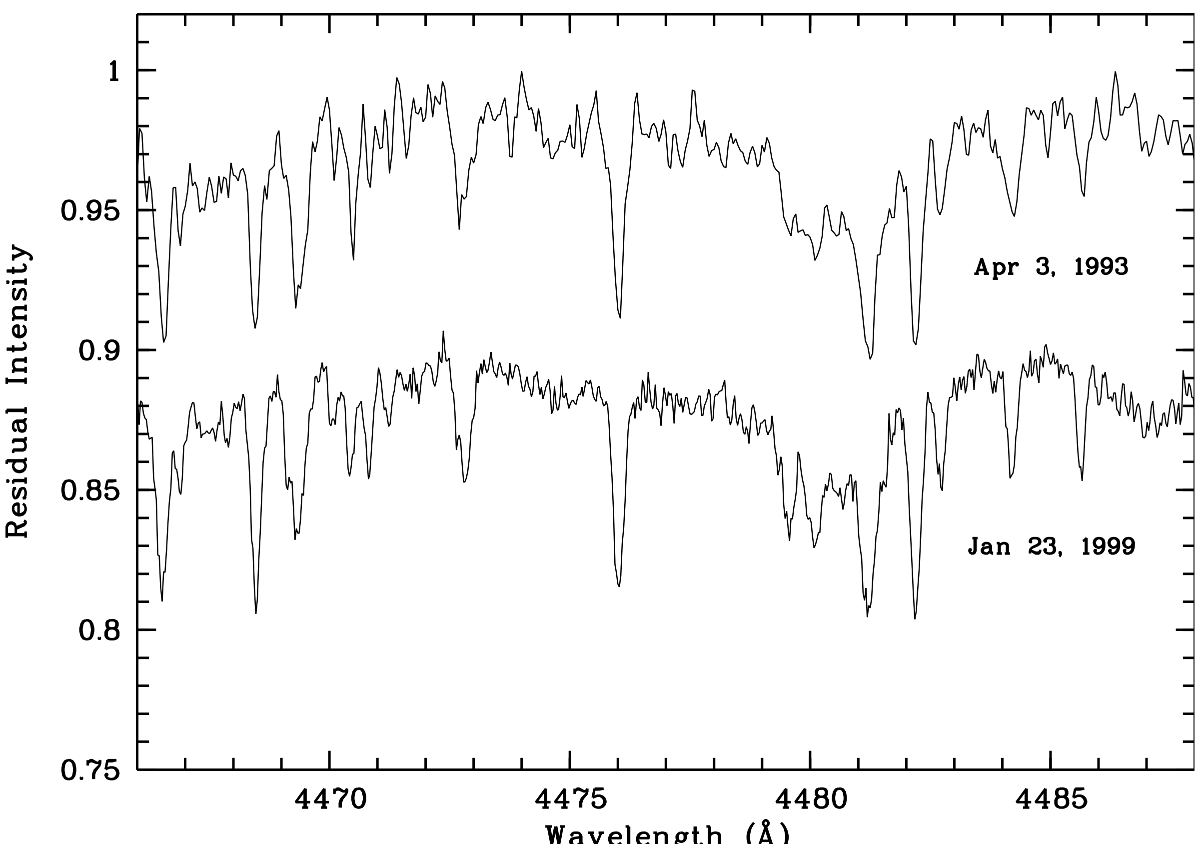

Fig. 13. Different profile shapes and asymmetries of narrow lines in the two spectra of HD 111786 observed at different epochs; the lower spectrum has been shifted by -0.1.

echelle spectrograph. It is installed in a thermally stabilized, humidity controlled room. The spectra are spread over 39 orders. The on-line DRS package running under MIDAS performed the bias subtraction, the flatfielding, the wavelength calibration, the optimal extraction of the orders and the merging of the orders.

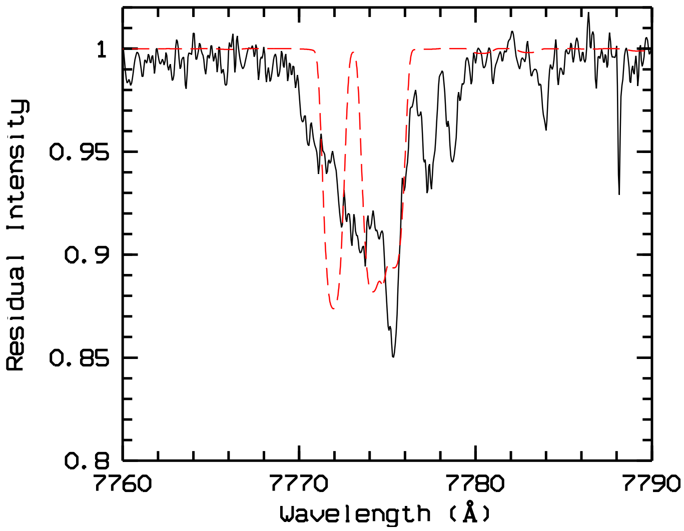

Fig. 12. The region of the O I triplet of HD 153808 compared with the spectrum computed using the model used in figures 10 and 11.

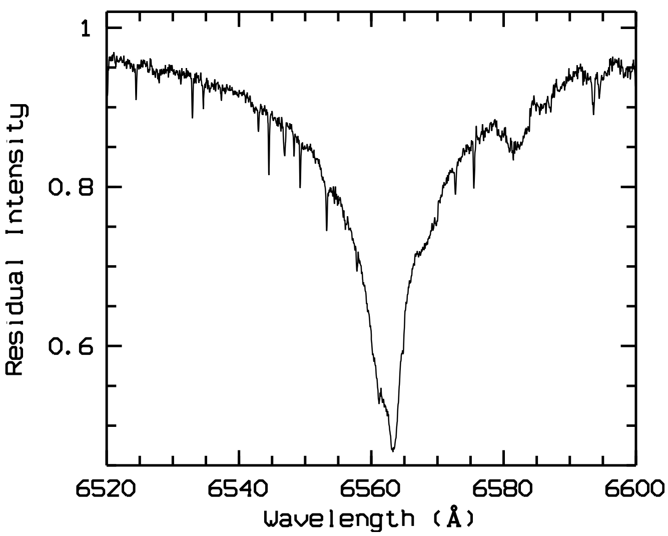

Fig. 14. The distorted Hα profile of HD 111786.

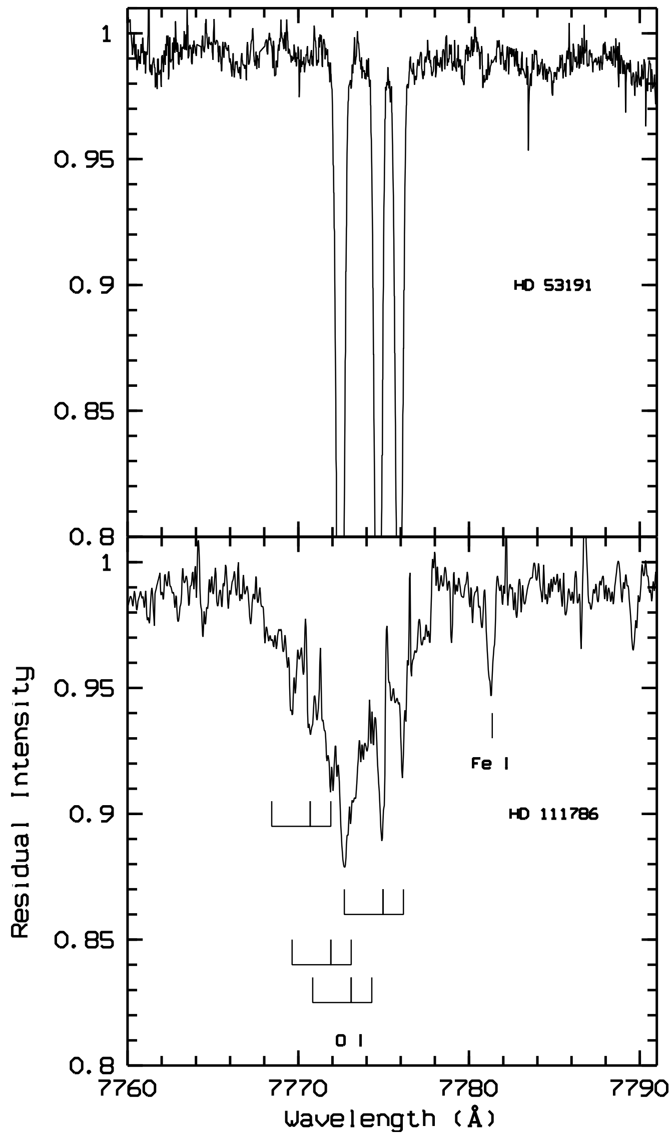

Fig. 15. The complex structure of the O I triplet 7772-7775 in the HD 111786 spectrum compared with the same feature in the low rotating A0 V star HD 53191.

Table 2. The observations

HD	J.D.	S/N	Instrument	range (Å)
18622	2447789.8875	100	Echelec	4200-4500
18622	2448524.8156	100	Echelec	4200-4500
18622	2448583.5424	60	Echelec	4200-4500
38545	2451621.3368	170	Musicos	5150-8800
38545	2451622.3403	260	Musicos	5150-8800
47152	2451622.2389	250	Musicos	5150-8800
47152	2451623.3750	180	Musicos	5150-8800
47152	2451817.6896	200	Musicos	5150-8800
84948	2451622.4583	210	Musicos	5150-8800
111786	2449084.6875	150	Echelec	4200-4500
111786	2451201.8243	160	FEROS	3800-8900
153808	2451622.6875	260	Musicos	5150-8800
153808	2451822.3333	210	Musicos	5150-8800

3.3. Musicos data

The Musicos spectrograph is mounted at the 2.2m Telescope Bernard Lyot of the Observatoire du Pic du Midi ; this echelle spectrograph has a fiber entrance corresponding to 2.1 arcsec on the sky. Through two different prisms it may cover the full optical range in two exposures covering the blue and red spectral ranges respectively, each containing 46 orders. We have only used the setting covering the 5150-8890 Å region. The photometric and wavelength reduction have been done directly at the telescope site by using ESpRIT (Echelle Spectra Reduction: an Interactive Tool), a computer code for online processing developed by Donati et al (1997) and made available at the telescope.

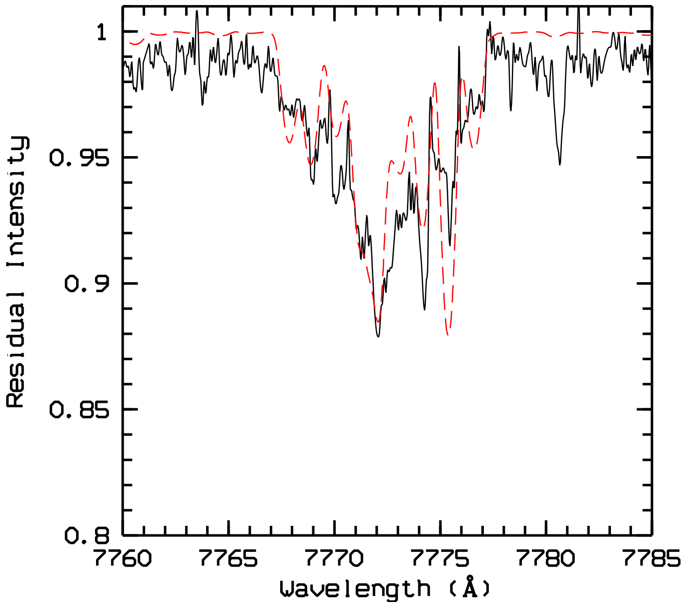

Fig. 16. The complex structure of the O I triplet 7772-7775 in the HD 111786 spectrum compared with that obtained by combining 4 synthetic spectra of slowly rotating stars (dashed line); see text for details.

3.4. IUE data

We inspected also IUE low and high resolution spectra extracted from the INES Archive. We used the low-resolution and the high-resolution rebinned images for the study of the flux distribution. The high-resolution spectra have been examined only for the echelle orders where shell lines are expected.

4. The spectra and their interpretation

The aim of this work is not to make any abundance analysis of these binaries, but only to detect and interpret the differences between the observed spectra and those computed with the hypothesis that these objects are single. The features more sensitive to these differences will be selected to be used to search other binaries among the λ Boo candidates.

The whole available spectral range for each star has been examined since the features most sensitive to duplicity are not necessarily the same for all objects; they depend on the atmospheric parameters and the magnitude difference of the binary system components. However, the wavelength regions that revealed a peculiar behaviour in most stars are the Balmer line cores, the O I 7774 triplet and the Na I 5890-5896 doublet.

We shall describe in detail for each of the 5 chosen binaries the signs of duplicity we have detected in the spectra at our disposal.

Table 3. Photometrically derived atmospheric parameters; the $v \sin i$ values are from 1) Slettebak et al (1975); 2) Abt & Morrell (1995); 3) Paunzen et al (1998).

HD	E(b-y) Moon	$T_{\rm eff}$ MD	log g MD	$T_{\rm eff}$ Gen	log g Gen	$v \sin i$ km s^{-1}
18622	0.000	8070	3.60	8048	3.47	60(1)
38545	-0.030	8600	3.59	8495	3.58	175(2)
47152	0.010	10190	4.22	10021	4.23	25(2)
84948	-0.030	6780	3.39	–	–	45,55(3)
111786	0.000	7490	3.95	7397	4.29	135(2)
153808	0.000	10130	4.20	9987	4.20	50(2)

4.1. Chosen atmospheric parameters for the computed spectra

The determination of $T_{\rm eff}$ and log g is obtained from the visual photometric colour indices by using the calibrations of Moon and Dworetsky (1985 (MD)) and Künzli et al (1997) of the uvbyβ and Geneva photometric colour indices respectively and by assuming the unrealistic hypothesis that the observed spectrum is produced by a single source.

The MD calibration is made for normal stars, but is valid for Ap stars too as discussed by Hubrig et al (2000, Appendix A); however, the extension to the low-blanketed spectra of λ Boo stars make sometimes doubtful the assignement to the groups defined in this calibration program. For example, Stürenburg (1993) [St93] chose the group 5 for all the stars of his sample, giving the priority to the spectral type A0-A3 of the stars he analyzed. On the contrary, we give the highest priority to the β index which is expected to be less sensitive to metallic lines; in fact the spectral classification can easily assign a too early spectral type to A stars with weak metal lines. Other criteria adopted by us are: the lowest resulting colour excess and the agreement with the parameters derived by other methods.

The Künzli et al (1997) calibration is used in the hypothesis that the colour excess is negligible as indicated by the Moon (1985) program results.

The parameters so derived are given in Table 3; the reddening is computed with the Moon (1985) program UVBYBETA and the $v \sin i$ values are taken from the literature.

The synthetic spectra are computed with Kurucz program SYNTHE and by using his line-blanketed LTE models Kurucz (1993). The composite spectra have been computed either with the Kurucz BINARY program or by combining the single synthetic spectra within MIDAS. Broadening velocities are adopted in order to fit the observed line widths.

4.2. HD 18622

This SB2 binary is chosen as an example of a "normal" star; its spectral variations are displayed in Fig. 1 and il-

lustrate how a single spectrum may be not sufficient to exclude the duplicity of a star. For this star, the very similar parameters of the two components make almost single the spectrum at the phase in which the lines are not resolved (see Fig. 2). This Figure shows the comparison between this observed spectrum and that computed with the parameters given in Table 3, but with $v\sin i$=75 km s^{-1}, value slightly higher than that given by Slettebak et al (1975). Even in this phase, where the star looks single, we note that several metal lines are stronger in the synthetic spectrum, so simulating globally a slightly weak-line star; in particular it must be noted that in the H_γ profile, the core is flatter than that computed, contrarily to what is expected and observed in single stars. The core of the Balmer lines is very sensitive to NLTE effect. When computed in LTE, using the Kurucz code, it should be less deep than the observed one, contrary to what is observed in Fig. 2.

The case of the normal HD 18622 demonstrates that it may be impossible, at certain phases, to detect the duplicity of an object without a careful comparison of observed with computed Balmer line profiles

4.3. HD 38545

The two spectra we examined are characterized by narrow components of several strong lines, in particular of H_α, of the Na I doublet and of several lines of Fe II.

The absence of narrow components on Mg II 4481 (see figure 11 in St93) and on the high excitation Fe II lines indicates that the narrow lines are due to a shell, not to a companion star, which would have affected these lines too.

The presence of these shell components prevents us from performing a detailed comparison between the observed spectrum and the two we have computed, one adopting the parameters chosen by us and listed in Table 3 and solar abundances, and the other with the St93 parameters and the metal abundances derived by this author. The two H_α profiles computed as for a single star, either by using the parameters given in Table 3 or with those adopted by St93 ($T_{\rm eff}$ =8970 K, log g=3.960, $v\sin i$=200 km s^{-1}) do not reproduce well the observed one (Fig. 3), however it is impossible to decide to what extent this is due to the duplicity and to what extent this is due to the presence of the shell.

The triplet structure of the O I 7772-7775 is washed out by the high $v\sin i$ of this composite spectrum; it appears as a single absorption feature; a simple abundance change in each of the two models would be sufficient to reproduce observations; so this OI 7772-7775 triplet is not a useful criterium to detect duplicity when its structure is masked by a high broadening.

This rapidly rotating star represents the class of objects for which the spectroscopic approach alone is not sufficient to prove the stellar duplicity. The comparison with synthetic spectra can only provide more or less convincing indications on duplicity from the inconsistencies between observations and computations.

4.4. HD 47152

HD 47152 (53 Aur) has been classified λ Boo by Abt & Morrell (1995), while it has been studied in the past as Ap of type Hg-Eu-Cr. The Catalano & Renson (1998) catalogue of Ap and Bp stars reports a photometric period of 2.80 d and Adelman & Pyper (1993) assign this star to the group of those with moderate to no spectral variations. The detection of the duplicity goes back to 1982 (McAlister & Hendry, 1982) and has been followed by 15 other papers on speckle measurements. However, the effect of the companion on the observed spectrum has never been taken into account in all the studies of this star, probably because these speckle data do not give information on the magnitude difference between the components of the binary system. The Hipparcos Catalogue data, giving a magnitude difference of ΔHp=0.77, clearly indicate that the observed spectrum must be affected by the presence of the companion star.

The two spectra we have taken show that the star is a spectroscopic variable; the Mg I triplet, plotted in Fig. 4, for example, is weaker on the second spectrum taken 1 day after the first one.

The spectral lines are narrow, so confirming the $v\sin i$ measured by Abt & Morrell (1995), however they are not fitted by the synthetic spectrum computed with the parameters given in Table 3 (but with $v\sin i$=30 km s^{-1}) and by assuming solar abundances. The wings of the H_α profile are reasonably well fitted by the computed spectrum (Fig. 5), but we note that the observed core is considerably less deep than that of the computed profile, contrary to what expected from NLTE effects which are not accounted for in our computations. The metal lines appear not to be weaker than expected for a star with these values of $T_{\rm eff}$ and log g so the λ Boo classification appears not to be justified for this star, at least at the phases of our observations. In the contrary, the high number of stronger than computed and of unidentified lines are in favour of the classification as Ap; however we remark some anomalies compared to classical Ap stars. The OI triplet at 7774 A is a very broad feature (Fig. 6) which may be fitted by a spectrum computed with $v\sin i$=300 km s^{-1}; we recall that the only previous mention of such a high $v\sin i$ is in Palmer et al (1968) where a value of 325 km s^{-1} is given for this star. Moreover this feature does not indicate the oxygen underabundance characteristic of Ap stars (see also Gerbaldi et al (1989) systematic study of this feature in Ap stars). We are not aware of any paper on Ap stars pointing out the discovery of non identified lines in the OI 7774 region.

The Na I doublet is very weak for the $T_{\rm eff}$ of 10000 K, the HeI 5876 is absent and the Fe I and Fe II lines would suggest a lower $T_{\rm eff}$, not coherent with the H_α profile. In fact several Fe II lines appear very weak compared with

predictions (e.g. 5166.033, 5197.577, 5316.615 Å), while the Fe I lines are systematically stronger than the computed ones. So several contradictory results obtained from the optical spectrum appearance suggest that HD 47152 is not a single object. We can also add that in the UV the h and k lines of Mg II and the strong Fe II lines in the range 2500-2600 Å have a broad profile, not coherent with most line profiles in the optical range.

Considering the high inclination (i=119.5^o) and the relatively long period (P=38.90 yrs) given in the IAU Inf Circ. Comm 26, No.142, 2000, it is likely that radial velocity variations may appear over a span of several years.

4.5. HD 84948

Moderate underabundances have been found by Paunzen et al (1998) for both components of this SB2 system. We adopted the same atmospheric parameters used by these authors to reproduce the spectrum at our disposal, i.e. $T_{\rm eff}$ =6600 and 6800 K, log g=3.3 and 3.7, $v\sin i$=45 and 55 $\rm km\,s^{-1}$ for each component respectively. The corresponding models have been computed by adopting the metal abundances derived by these authors and we computed the synthetic spectra with the same quoted value of the microturbulence (v$_{turb}$=3.5 $\rm km\,s^{-1}$ for both components) and adopting the hypothesis of these authors that the two stars have almost the same luminosity. The observed H_α line is used to derive the relative radial velocity of the components at the epoch of our observation: the values we found are -77 and +70 $\rm km\,s^{-1}$respectively. The resulting combined synthetic spectrum is displayed in Fig. 7 superimposed on the observed one. We note that while the redshifted component is well fitted, the reverse is true for the other component; any small change in the luminosity ratio will worsen the fit of the redshifted component and does not produce more convincing results for metal line profiles. The fit of the NaI doublet (Fig. 8) and of the OI 7774 triplet (Fig. 9) confirm that the parameters for the higher rotating star do not reproduce the observations; they may even suggest that this component is indeed a double star. Also the other metal lines are not fitted by this computed spectrum, so that we cannot confirm the abundance values reported in the above quoted paper.

This object shows that it is not easy to produce a combined spectrum of an SB2 star that matches the observed one because many free parameters have to be taken into account and so it may happen that in a narrow wavelength range the observed spectrum is roughly fitted by a computed one, even if the adopted parameters are not the real ones.

Moreover this kind of analysis does not have any sense if made on one or few spectra; in fact a careful check that the combined spectrum is not variable with the period is necessary to exclude the partial eclipse possibility.

The bad fit with the combination proposed by Paunzen et al (1998) may be interpreted either as due to a choice of parameters that must be revised, as it can be expected from the inconsistency of the difference in log g of the two components and the adopted almost equal luminosities, or as sign of variable spectrum.

4.6. HD 153808

The two spectra at our disposal, even if the one taken on October 4th has a lower S/N and is affected by strong H_2O telluric bands, clearly confirm that the star is an SB2; a more subtle check of the March 18th spectrum made through the comparison with a synthetic spectrum computed from the model with $T_{\rm eff}$ and log g given in Table 3, but with a lower value of the broadening (30 $\rm km\,s^{-1}$), reveals that the H_α profile (Fig. 10) of the blue-shifted component is distorted, suggesting that it is probably due to two sources. This duplicity is supported by the complex structure of the O I triplet at 7774 A (Fig. 12) and more evident in Fig. 11 where the region of the Na I doublet and He I 5876 is compared with the same computed spectrum.

The cooler component is responsible for the strong and red-shifted component of the NaI doublet and for the FeI 5914 line, but does not contribute to the He I 5876 absorption. The hotter blue-shifted (on the plotted spectrum) component of the NaI doublet presents a double absorption which has the same profile and separation as that of the HeI 5876 line. These profiles are interpreted as a signature (together with the H_α core profile) of duplicity of the hotter component of this system.

The considerable difference in the atmospheric parameters makes the star brighter in the red that appears fainter in the photographic blue range examined by Petrie (1939) and the high resolution of Musicos allowed us to detect the presence of a third component.

Lambert et al (1986) by adopting $T_{\rm eff}$ =9700 K, log g=4.00 and $v\sin i$ =38 $\rm km\,s^{-1}$ derived log$\epsilon(C)$=7.68 from lines at λ=9000 Å; this extreme C deficiency is discussed in detail by these authors and the possibility of a companion examined.

The present study clarifies that this object is a triple spectroscopic system and not a λ Boo star.

This star is an example of spectroscopic triple system with a too small angular separation of the components to be detected by Hipparcos (ESA, 1997) or by speckle interferometry (Marchetti et al, 2001). This example demonstrates that a single most efficient approach to detect all the λ Boo binaries does not exist, since we cannot make *a priori* any guess on the angular separation of the possible components.

5. Binary detection criteria from spectrum inspection

The fact that newly detected binaries have been found among stars already well studied indicates that the two components of these systems have similar parameters; this fact combined with the quite high value of $v\sin i$, characteristic of A-type stars (not belonging to the Ap-Am

classes) stars, makes it very delicate to detect the duplicity and an abundance analysis based on the average atmospheric parameters may be done by lowering metal abundances in order to compensate the veiling effect. If the two components of a binary system are similar, the average spectrum is expected to be similar to that of each component; this is the case of HD 38545 for which only mild underabundances have been derived (St93). A larger difference of the two sources is expected to produce larger apparent abundance peculiarities as in the case of HD 47152, classified either Ap or λ Boo .

We have shown that even a triple system can be confused with a single peculiar star when the anomalous line intensities are attributed only to abundance anomalies, as in the case of HD 153808.

If one allows all the abundances to be fitting parameters, spectral synthesis will provide a reasonable fit to the data in almost all cases, even though the fitting abundances are totally unphysical. In the previous section we have shown that a very careful inspection of any observed spectrum is mandatory before starting any abundance analysis of an object that has a mean-high $v \sin i$ value. We have shown that this is not an easy task and we have selected the spectral features that are the more promising for A-type stars and that may be different for different binaries.

The example of HD 18622 has been given to underline the importance to have more than a single spectrum; an SB2 may not be detectable at certain phases.

From the inspection of the other spectra we learned that for rapidly rotating stars, most of the absorption lines are in fact blends and the less contaminated features of species present over a large interval of stellar $T_{\rm eff}$ are the best suited for such detection. We have selected in this way the O I 7774 triplet as the most helpful reference for stars with a moderate value of $v \sin i$: see figures 6, 9 and 12 .

The absorption core of the Balmer lines which is broadened mainly by Doppler effect is expected to be deeper than that computed in the LTE approach while it is flatter in composite spectra. But the intrinsic difficulty to trace a very accurate continuum in the region of Balmer lines for dwarf A-type stars spectra must not be neglected, due to the fact that the maximum extension of the wings of these lines appear in the $T_{\rm eff}$ range around 8500 K.

The detection of unidentified lines must be carefully checked with some reference star spectrum; in fact that may simply indicate a displaced absorption by a companion star; the presence of these lines is easier to detect at long wavelength where the line crowding is less important.

The period of spectroscopic binaries is usually short; so more than 1 spectrum taken during an observing run should be sufficient to detect not very rapidly rotating SB2 stars.

It should be noted that we have not discussed in detail the comparison between the observed and the computed flux distribution; in principle this can be a further criterion to recognize binaries if the two components have not equal $T_{\rm eff}$. In practice, this comparison is rarely efficient because based, for most stars, on photometric magnitudes and the calibration of these values are affected by uncertainties of the same order that the differences we are looking for.

The discrepancies we have found in making these comparisons could be explained either by the duplicity or for the above reasons and therefore we consider this approach a valid method only if relative comparisons are made between objects observed with the same photometric filters for visual and IR.

When this comparison is restricted to the UV range covered by IUE spectra the main sources of uncertainty are represented by the accuracy of the computed line blanketing and by the rôle of the NLTE on the metal b-f discontinuities. The comparison in this range requires accurate computations of the heavy line blanketing and of the b-f transitions. In fact these can be significantly different in real metal deficient stars as the λ Boo are supposed to be and in stars with solar abundances.

So, in general, only complementary information can be obtained for suspected complex objects when peculiarities are found in the UV range not coherent with what is expected from the visual range analysis. This is the case with HD 38545 whose UV flux suggests a lower $T_{\rm eff}$ or a higher blanketing than the optical spectral analysis and of HD 111786 (the star we shall discuss in the next Section) whose high UV flux suggests a higher $T_{\rm eff}$ or a lower blanketing than that indicated by the optical spectrum.

6. Application to the case of HD 111786: a complex object, not a λ Boo star

HD 111786 (HR 4881) has been assigned to λ Boo class by Andersen and Nordström (1977) and since then accepted by all the following authors. The Hipparcos Catalogue (ESA, 1997) gives its parallax (16.62 $\pm$ 0.72 mas), and no sign of duplicity is mentioned.

Faraggiana et al (1997) discovered the duplicity of this "λ Boo star" on the basis of the double core of the H_γ profile and of the set of narrow lines superimposed on the broad features in the examined optical spectrum (covering the limited wavelength range of 300 Å from 4200 to 4500 Å). They showed also that a combination of two theoretical spectra both computed with *solar abundances*, $T_{\rm eff}$ = 7500 K, log g = 4.0, but with different $v \sin i$ (10 and 150 $\mathrm{km\,s^{-1}}$) simulates qualitatively the observed spectrum. Moreover the high UV flux and the absence of the narrow line components at wavelength shorter than 2000 Å suggested that the broad component was slightly hotter than the other.

On the basis of these indications, we made many attempts to reproduce the observed composite spectrum by combining two theoretical spectra; a rough, but not good fit was obtained for the spectrum covering the 4200-4500 Å range, by combining two spectra computed from Kurucz models with solar abundances, log g=4 for both components, $T_{\rm eff}$ =7750 and 7200 K, $v \sin i$=250 and 20

$\mathrm{km\,s^{-1}}$, relative luminosities=0.7 and 0.3 and a radial velocity difference of 50 $\mathrm{km\,s^{-1}}$. A real good fit has never been achieved by introducing slightly different parameters and various differences in the luminosity ratio of the two components and we were left with the doubt that the system is more complex than a simple binary.

The experience gained by the analysis of the binaries discussed in previous sections suggested to examine a spectrum taken with higher resolution and covering a much broader wavelength domain than that previously used.

Contrary to HD 38545, in HD 111786 the narrow lines cannot be due to the presence of a shell; in fact all the spectral lines present the narrow components, not only those characteristic of stellar shells (i.e. the resonance or low excitation lines and those arising from a metastable level from which the atom cannot cascade to a lower level in a permitted transition); even Mg II 4481 (lower E.P.=8.83 eV) presents the complex profile corresponding to broad and narrow components. The broad line component is the predominant one and that on which the abundance analysis by Stürenburg (1993) is based; see also Fig 12 of his paper. The complex and variable profiles of the narrow lines denote their complex origin which is due to more than one low rotating source (Fig. 13).

All the Balmer lines present a splitting of the core, but if a simple duplicity could have been derived from the H_δ double core, the more complex multiplicity of this object appears from H_α whose profile shows the contribution of several components. The increasing contribution of cooler components of this system appears also from the increasing complexity of metal lines features toward long wavelength. The profile of the O I triplet 7772-7775 which lies in a spectral region not contaminated by other lines contribution is plotted in Fig. 15 together with the same region observed in the low rotating A0 V HD 53191. The complex feature observed in HD 111786 is composed by a broad blend due to a high rotating star ($v \sin i$ at least 150 $\mathrm{km\,s^{-1}}$) (in the not proved hypothesis that this profile component is due to a single source) and by 4 or more other narrow sources, one of which is slightly brighter than the others. We have produced the computed spectrum plotted in Fig. 16 by combining a synthetic spectrum computed with the model $T_{\rm eff}$ =7250 K with three others with $T_{\rm eff}$ =7750 K shifted by -157.0, -118.5, +46.0 $\mathrm{km\,s^{-1}}$with respect to the first one; all these spectra have been computed by assuming a broadening of 20 $\mathrm{km\,s^{-1}}$ and therefore the dominant broad-lined component is not included. We do not claim that this combination is a faithful reproduction of the observed spectrum, but we only want to demonstrate how such a complex morphology may indeed arise due to stellar multiplicity.

The two examples in figures 15 and 16 show the complexity of this system and the existence of multiple distinct solutions. So, the analysis of the profile of the OI 7774 triplet in particular, clarified the problem of the high multiplicity of this star.

HD 111786 appears to be formed by a clump of at least 5 stars and therefore we cannot hope to make any reliable abundance analysis of this object revealing possible abundance anomalies. If we accept the definition of λ Boo stars as single objects with peculiar atmospheric abundances then *the classification of this complex object as a λ Boo star must be definitely rejected*.

7. Conclusion

Faraggiana & Bonifacio (1999) suggested that binaries can be easily confused with λ Boo stars when their classification is based only on classification dispersion spectra. The detection of binaries with the spectrum affected by a companion, i.e. of objects producing a composite spectrum, is the fundamental first step before making any abundance analysis on which more or less elaborated theories to explain these stars will be based. However, the detection of binaries among these stars is subtle; the systems already detected show that the components of each system have a slight difference in stellar parameters so that an abundance analysis based on the average value of the atmospheric parameters does not produce absurd results.

Most of the double systems that have been already recognized as such have an angular separation lower than 1 arcsec, i.e. below the limit of most spectrographs entrance aperture. Most λ Boo stars have mean-high $v \sin i$ and the detection of duplicity on the basis of spectra only remains often doubtful.

As a consequence several complementary approaches must be considered; the most promising techniques are speckle, adaptive optics and interferometry, but still a large gap in the angular separation is expected to remain between the limits of interferometric and spectroscopic detection.

In the present paper we used the last approach and presented the results of search for criteria that can reveal the stellar duplicity from the inspection of high quality spectra covering a large wavelength range. Isolated features, as the OI 7774 triplet, the NaI doublet, the core of the Balmer lines, and the general fit between observed and computed profiles appear to fulfill our purpose.

This study allowed us to recognize that HD 153808 is a triple spectroscopic system.

The application of these selected criteria to a λ Boo candidate, HD 111786, revealed the complex nature of this object, which is not a single peculiar star surrounded by a shell as presented in the literature, but a clump of at least 5 components.

Acknowledgements. Use was made of the SIMBAD data base, operated at the CDS, Strasbourg, France. RF acknowledges grants from MURST 40% and 60% and from the University of Trieste.

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